8.9 DETECTION OF AIRBORNE VOLCANIC ASH WITH GOES: ISSUES AND PROSPECTS FOR THE COMING DECADE

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1. INTRODUCTION

Geostationary Operational Environmental Satellites (GOES) provide an excellent platform for monitoring hazardous airborne volcanic ash clouds due to their high imaging frequency, multi-spectral capabilities, and good resolution (1 km visible, 4 km Infrared (IR)). Current scanning strategies using the five channel GOES Imager allow monitoring of most volcanically-active regions in the GOES viewing area every 30 min. Imagery commonly used includes single band visible and IR, plus multi-band derived products.

Brightness temperature differences between IR bands at 12.0 and 10.7 µm (known as the Two-Band Split Window (TBSW)), originally developed with Advanced Very High Resolution Radiometer (AVHRR) data from the NOAA polar orbiting spacecraft (Prata 1989), have recently been applied to GOES data (Davies and Rose 1998). The TBSW technique has been successfully employed at operational Volcanic Ash Advisory Centers (VAACs) in North America since first becoming available with GOES-8 in 1994. More recent multi-spectral techniques that use the 3.9 µm shortwave IR and visible bands, along with the TBSW have been described by Ellrod and Connell (1999), and Mosher (2000).

Beginning with the GOES-12 spacecraft (launched July 23, 2001 and checked out by November 2001) through GOES-Q (late 2008 launch), the 12.0 µm band (4 km) on the GOES Imager will be replaced by a 13.3 µm channel (8 km). The nineteen channel GOES Sounder, which continues to have the 12 µm channel, will remain unchanged. The operational use of the Sounder is not as effective as the Imager however, due to its lower resolution (10 km) and image frequency (hourly at best) (Ellrod 1998). This paper describes an assessment of the operational effects of the loss of 12 µm IR data, recommends alternative strategies needed in order to maintain the integrity of the operational volcanic ash alerting system, and provides a glimpse of future GOES capabilities.

2. LOSS ASSESSMENT

A loss assessment study has been completed using GOES-8 Imager and equivalent Sounder channels for nine weak to moderate eruptions (Ellrod 2001), and for one very small emission observed during GOES-12 checkout on 9 October 2001. The benefit of using the Sounder in this assessment is that it has the 13.3 µm channel, which will replace the 12 µm band on GOES-M through Q. Qualitative assessment was completed by generating principal component images (PCI) with and without contribution from the 12 µm IR band, then comparing the best available images for clarity of the ash cloud. The PCI were produced on a Man-computer Interactive Data Analysis System (McIDAS), using software developed by Hillger (1996). The "true" location and extent of the ash cloud was estimated with the help of (1) all available IR products, (2) daytime visible images, and (3) operational text and graphic advisories from the Washington VAAC. In one case (26 December 1997) a concurrent Total Ozone Mapping Spectrometer (TOMS) Aerosol Index image was obtained as an independent source of ash coverage.

A comparison derived from GOES Imager data is shown in Figure 1 for a moderately strong eruption of Guagua Pichincha volcano near Quito, Ecuador on 5 October 1999. In this case, there was considerable cloudiness in the area, with deep convective clouds (thunderstorms) to the north. The top two PCI images clearly show the ash cloud (outlined), but the one without the 12 µm band (middle panel) shows "false ash" in southern Columbia. This highlights the importance of the 12 µm IR data in discriminating ash from cirrus cloud. However, a simple TBSW image (bottom) did not show the ash clearly, likely due to contamination from extensive cloud cover. Evaluation of the Guagua Pichincha ash cloud evolution using animated GOES images indicated that some of the volcanic cloud was not clearly identified in this imagery, even with the benefits of the 12 µm IR data. This under-detection could be due to (1) the presence of considerable ice content, (2) opacity of the cloud, or (3) contamination by ambient moisture. All three factors have been noted to reduce the effectiveness of the TBSW method (Rose et al 1995; Potts and Tokuno 1999; Simpson et al 2000).

A PCI image was produced during the GOES-12 Science Test for a weak ash emission of Popocatepetl in Mexico on 9 October 2001. The GOES-12 depiction of the ash "puff" was smaller in area than shown by GOES-8 data (Figure 2). This is partially due to the 8 km resolution of the 13.3 µm band data, compared with 4 km for 12.0 µm, which results in "smearing" of the cloud edge. For large ash clouds, this effect will be minimal.

A quantitative parameter, termed "False Pixel Rate" (FPR) was also estimated for many of the cases. The

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FPR describes the percentage of the total image area (in pixels) comprised of "false ash" (based on the subjective "true ash" cloud described above). This can be described as:

$$FPR = (T - A) / N \qquad (1)$$

where T is the total of ash plus false pixels, A is the number of "true" ash pixels, and N is the total number of pixels in the image scene.

A daytime FPR analysis is shown by the histogram in Figure 3 for the Guagua Pichincha eruption described previously. At 2015 UTC (~1.5 hr after eruption), the FPR value is >5 times larger for the PCI image that includes the 12 µm band than the image without it, due to the opacity of the volcanic cloud caused by heavy concentrations of large ash particles, water droplets and/or ice. At 2115 UTC, the FPR is 3% for the images with and without 12 µm contribution. The increase in the latter to ~5% by 2215 UTC is due to reduced solar reflectance as sunset approaches, a major component of the 3.9 µm IR contribution. The role of reflectance at shortwave IR wavelengths has been described by Schneider and Rose (1994) based on Mt. Spurr volcano ash samples in Alaska.

Analysis of GOES Sounder data for an ash cloud from Popocatepetl on the night of 23 January 2001 over eastern Mexico resulted in an FPR rate that was ~5 times higher without 12 µm data. The addition of the 13.3 µm IR channel provided only a slight improvement, due to the sparsity of cirrus clouds present in the area.

3. OPERATIONAL EFFECTS

Subjective evaluations of the eruption cloud images indicated that most mis-identified ash is not contiguous with the "true" ash plume or cloud. This suggests that a VAAC analyst can track an ash cloud, and provide a reasonably good estimate of its area, using subjective pattern recognition in many cases. The ability to animate GOES imagery at 15 to 30 min intervals is critical in providing continuity in this analysis. However, some under-detection of very thin ash is likely to occur without the benefit of 12 µm data. The 13.3 µm data has been found to be useful for thin cirrus discrimination.

The results of this assessment study indicate that there will most likely be some degradation of ash detection capability, especially at night, but that human analysts armed with animated imagery will still be able to identify and track ash clouds, and issue timely advisories for aircraft avoidance. One possible operational effect of the degradation is that due to uncertainty in the location of thin ash, analyzed ash clouds will be enlarged in area to err on the side of safety, resulting in longer enroute diversions.

4. RECOMMENDATIONS FOR GOES M-Q

Recommendations for optimal IR volcanic ash detection during the next 10 years using the reconfigured GOES Imagers stress the need to utilize the 3.9, 10.7 and 13.3 µm bands, as well as other remote sensing platforms. The three most viable options are:

(1) "Reflectivity Product" based on the difference of 3.9 and 10.7 µm IR
(2) Tri-spectral PCI using 3.9, 10.7 and 13.3 µm IR bands
(3) Increased use of other resources (such as the GOES-Sounder, AVHRR and NASA Earth Observing System (EOS) platforms), especially for long-lived eruptions

Most of these capabilities are already in place at the Washington VAAC. Data from the 36-channel, 1 km resolution Moderate resolution Infrared Spectro-radiometer (MODIS) will soon be available at the Washington VAAC via a high speed data link from the National Aeronautics and Space Administration. VAACs at Montreal and Anchorage already utilize AVHRR data from the NOAA spacecraft, in addition to GOES.

5. FUTURE CAPABILITIES

Early in the next decade (circa 2013), an Advanced Baseline Imager (ABI) will be implemented on GOES-R, providing greatly improved volcanic ash detection capability. Although planning for ABI is still ongoing, it will likely have a minimum of 12 spectral bands (including restoration of the 12 µm band), at twice the resolution (2 km IR, 0.5 km visible), with faster scanning that allows frequent global coverage (no regional conflicts as with the current Imagers). Additional channels are also being considered (centered near 7.4, 8.5, and 9.6 µm) to provide detection of both ash and SO_2 gas emissions, a unique indicator of significant volcanic activity. An example of the potential of this capability is shown in Figure 4, a MODIS PCI image at 20 February 2001, 0845 UTC, for an ash cloud from Cleveland Volcano in the Aleutians. The MODIS channels contributing most to the detection of the ash in this image were centered at 4.5, 8.6 and 12.0 µm.

6. SUMMARY AND CONCLUSIONS

The reconfiguration of the GOES Imagers beginning with GOES-12 launched in 2001 will result in some degradation of our volcanic ash detection capability, especially at night. Some recommendations for mitigating this loss involve multi-spectral combinations of existing Imager channels, and increased exploitation of higher resolution polar orbiting spacecraft. The Advanced Baseline Imager on GOES-R (~2013) promises to provide greatly improved capability that could allow automatic detection systems to be developed.

7. ACKNOWLEDGMENT

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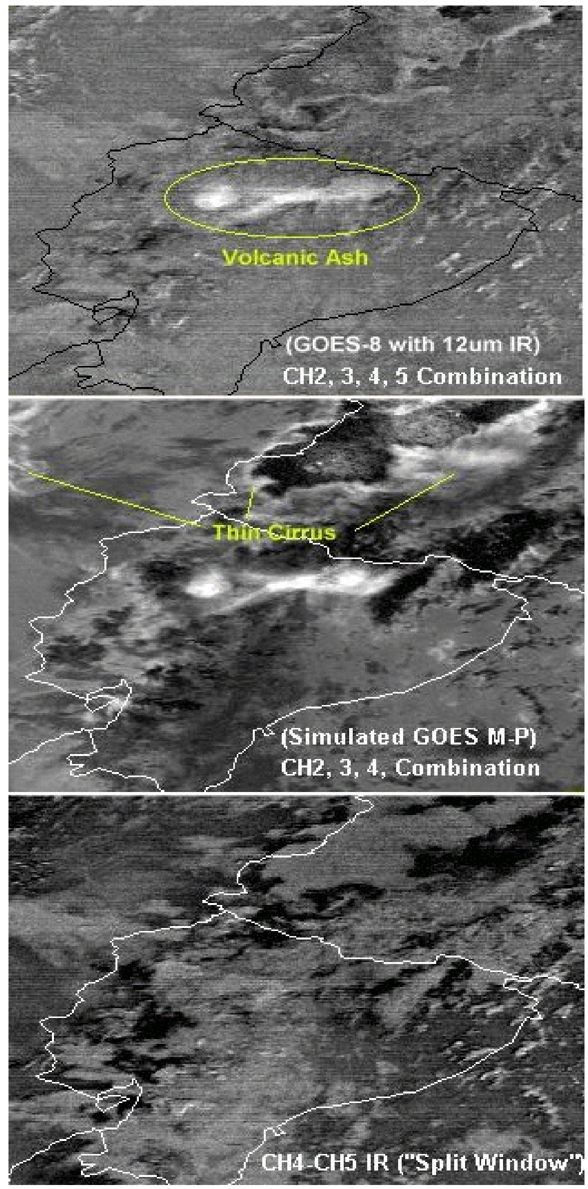

Figure 1. Principal component images derived from GOES Imager on 5 Oct 1999 at 2215 UTC for eruption of Guagua Pichincha in Ecuador. Top image uses all five bands, including 12.0 µm, middle image uses only Bands 2, 3, and 4, and lower image is based on TBSW (Band 5 -4).

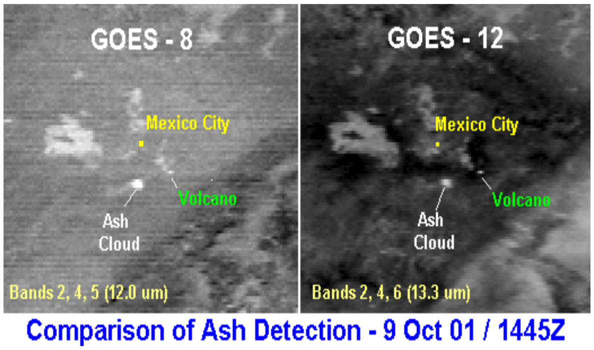

Figure 2. Principal component images from GOES-8 (left) and GOES-12 (right) depicting a small ash emission from Popocatepetl on 9 October 2001. Time of both images is 1445 UTC. GOES-12 image is based on 3.9, 10.7, and 13.3 μm IR bands.

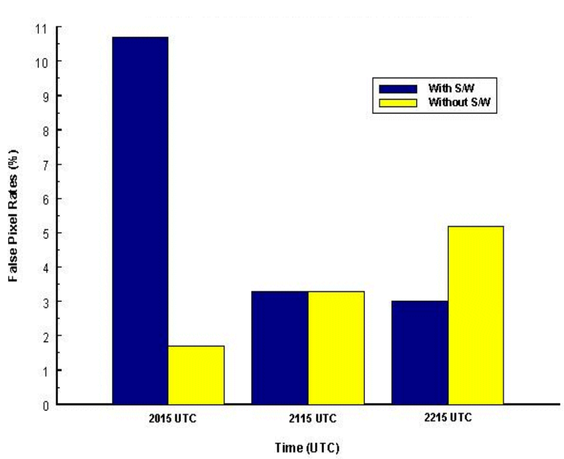

Figure 3. False Pixel Rates (%) from GOES Imager on 5 Oct 1999 for eruption cloud from Guagua Pichincha in Ecuador. Black bars are for images that include contribution from 12 μm IR band. Gray bars do not.

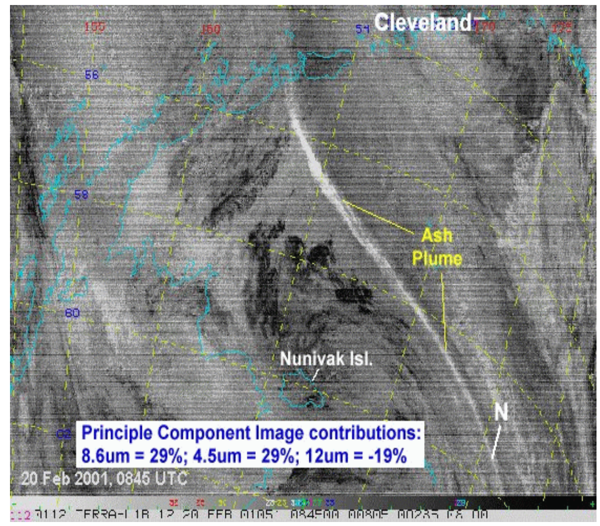

Figure 4. Principal component image derived from MODIS on 20 Feb 2001 at 0845 UTC for an ash cloud from Cleveland volcano (top). Legend shows percentage of explained variance for spectral bands that contributed the most to the image. (From D. Hillger, NOAA/NESDIS)